A Study on the System Design of Buoy-Type Automatic Water Quality Monitoring Equipment Based on KJ-AHP

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Abstract. Water resources are vital to human society and natural ecosystems, and water quality monitoring, as an important means of detecting and evaluating water resources, is able to understand the pollution of water bodies in a timely manner and make predictions, which provides an important scientific basis for the protection of water resources and the maintenance of ecosystems. This paper explores the application of the KJ-AHP method in the design of buoy-based water quality monitoring equipment. Firstly, the KJ method (Affinity Diagram Method) is used to sort out the product requirements of water quality monitoring equipment in market products and literature materials; the weights of the indicators are calculated through user interviews, questionnaires and the Delphi method, and one target layer, four first-level indicators, and twelve second-level indicators are screened out; then another round of expert questionnaires is carried out, and the performance demand hierarchical model of the buoy water quality monitoring equipment is constructed and the consistency test is completed; the conclusions of the study are applied to the design of a new buoy water quality monitoring equipment, and the design of a new buoy water quality monitoring equipment is developed. Consistency test; Apply the research findings to design practice, combined with automatic water quality monitoring technology, from the functionality, intelligence, safety and aesthetics of the product, to design a buoy-type water quality monitoring equipment. This design study not only helps to improve the practicality and aesthetics of the water quality monitoring equipment, but also provides a useful reference for further innovation and improvement in the field of water environmental protection equipment.

Keywords-AHP hierarchical analysis; Water quality monitoring equipment; KJ method

1 Introduction

Water is the source of life, not only for human society, but also an important pillar of the ecosystem.Water quality plays an important role in any aquatic system, e.g., it can influence the growth of aquatic organisms and reflect the degree of water pollution [1]. Increasing water pollution in oceans, lake, and river triggers worldwide demand more advanced methods in environmental monitoring systems particularly in the field of water quality monitoring [2]. Advances in modern technology, especially the application of Internet of Things (IoT) technology, Artificial Intelligence (AI) and big data analysis, provide us with unprecedented opportunities, which also means that we can obtain information and take measures more

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quickly, accurately and comprehensively to predict the quality of the water body, curb the spread of pollutants, and repair damaged ecosystems.

To achieve automated monitoring of water quality, it is necessary to rely on sensors and automated equipment to collect water quality parameters, through the collection of various types of key indicators, such as dissolved oxygen, turbidity, total phosphorus, total nitrogen, COD, etc., in order to understand the overall trend of water quality. The general water quality automated monitoring process is mainly: sample extraction; data transmission; data analysis; visualisation system interface. In addition, through long-term monitoring and analysis of water quality data, combined with the deep learning ability of AI will identify patterns and laws of abnormal changes in water quality [3].

Intelligent environmental protection integrates technologies such as artificial intelligence into environmental emergency management and environmental monitoring. It utilizes big data for risk assessment and analysis, thus proposing intelligent solutions for environmental governance. AI empowers the field of water quality monitoring, allowing algorithms to act as decision assistants. It also alleviates the workload of professionals and enhances work efficiency. With the application of AI technology in various types of sensory acquisition of sensor equipment is becoming more and more abundant, the key technology and equipment is becoming more mature, AI edge computing intelligent terminal and data intelligence platform strong association will become a trend [4].

In China, the Ministry of Water Resources issued the Notice of the Ministry of Water Resources on the Early and Pilot Work of Digital Twin River Basin Construction, which plans to use about 2 years to carry out the early and pilot work of digital twin river basin construction in the key sections of large rivers and major tributaries [5], which makes it clear that the digital twin technology will be the core and the key of the smart water resources. Monitoring and early warning, as an important part of water resources management, should also be combined with digital technology to achieve the goal of accurate analysis, simultaneous preview and dynamic evaluation. In summary, it seems that research institutions at home and abroad in the field of water quality monitoring equipment research is mainly focused on sensing technology innovation, automated monitoring systems, artificial intelligence and big data analysis and other directions, is committed to improving the accuracy, efficiency and intelligent level of water quality monitoring.

As an automated water quality monitoring system integrating data collection, transmission and processing, the buoy-type water quality monitoring station has the features of high efficiency, small size, wide distribution and convenient installation, which is of great significance in the aspects of prevention and control of water pollution and management of water bodies by environmental protection organisations and government departments. Therefore, this study to buoy-type water quality testing equipment as the main research object, combined with the market has buoy-type water quality testing equipment and part of the concept of water quality and environmental protection equipment modelling and functionality, market style and future trend analysis ‘Figure 1’, found that the current water quality monitoring equipment is mostly focused on a single function and modelling of the mechanical nature of the strong, and the axis of the style map clearly shows that the product is to the intelligent and multi-functional direction of development. Based on the above trend analysis, I will further upgrade the buoy type water quality monitoring equipment and design a new water quality monitoring equipment and its operating system.

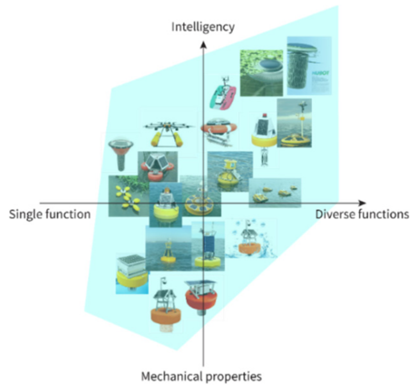

Figure 1. Coordinate diagram of water quality monitoring equipment style.

2 Methods--KJ-AHP

This paper calculates the importance ranking of various performance indicators of the buoy-type water quality monitoring equipment based on the affinity diagram method and the hierarchical analysis method, and carries out the innovative design practice of the buoy-type water quality testing equipment according to the research results, so as to obtain a more novel, beautiful and powerful water quality monitoring equipment (the research framework is shown in 'Figure 2').

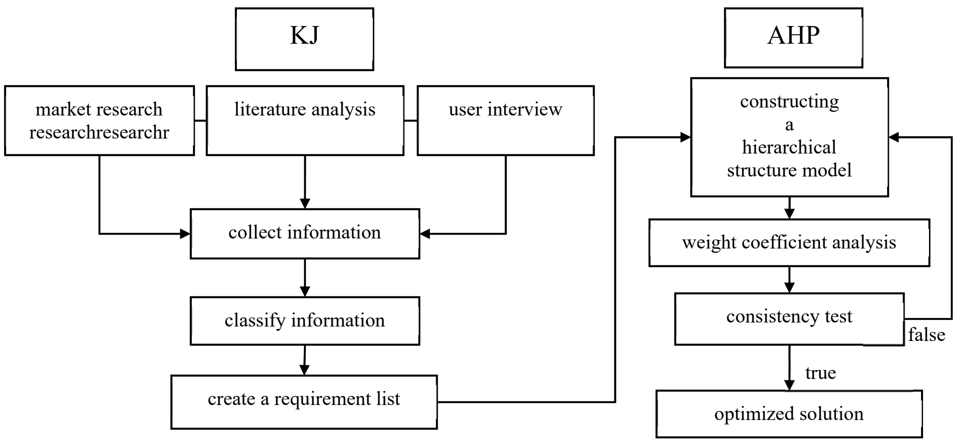

Figure 2. The research framework.

2.1 The KJ method

The The KJ method, also known as the affinity diagram method, proposed by Jiro Kawakita, is a method that collects a large amount of existing facts, opinions, or assumptions in a chaotic and disordered state of a new field of study, uses the interrelationships between them to categorise and synthesise them, and expresses them in a rational graphical representation.The KJ method facilitates the clarification of thoughts to discover the whole picture of the problem and find a way to solve it [6]. This method can integrate the clutter of ideas and information through the correlation between them [7], and find a relatively clear design intention to produce a targeted design strategy. The performance requirements of water quality monitoring equipment involve multiple levels, fields and indicators. In the demand analysis and selection process, the collected information is categorised and integrated with the help of the KJ method by collecting mainstream buoy-based water quality testing equipment and new unmanned monitoring vessels in the market, asking relevant experts and designers for their opinions. Finally, the hierarchical model of buoy water quality monitoring equipment is determined: one target layer (A hierarchical performance requirements of buoy water quality testing equipment); four quasi-measurement layers (B1 functionality, B2 intelligence, B3 safety, and B4 aesthetics); and the programme layer (C11 early warning function, C12 evaluation function, C13 physicochemical analysis, C14 multi-parameter monitoring, C15 positioning function, C16 obstacle avoidance function, C17 transparent platform, C21 automatic monitoring, and C22 model prediction, (C23 Risk Assessment, C24 Regular Report Generation, C25 Route Planning, C31 Water Resistant Design, C32 Impact Resistant Enclosure, C33 Device Anomaly Alert, C34 Data Security, C41 Natural Style, C42 Modern Technology Style, C43 Bright and Vibrant Style, C44 Environmental Integration, C45 Clarity and Transparency).

2.2 Analytic Hierarchy Process

The Analytic Hierarchy Process is a method of "measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales" [8]. There are six phases in this method [8,9]: Define the problem and determine the kind of knowledge sought. Structure the decision hierarchy. Structure the decision hierarchy. Construct matrices to calculate a set of pairwise comparison. Calculate the relative weight of the elements to each level. Check and balance of decision. Decision documentation.There are more demand indicators to be collected in product design, using AHP model can reduce the personal subjective influence of decision makers, objectively and efficiently complete the extraction of important demands, and endow the design with rationality. The Delphi technique is a group process used to survey and collect the opinions of experts on a particular subject [10]. The screening was first carried out by the Delphi method, and the original programme layers were screened by weighting values through two rounds of Likert scale questionnaires distributed to the experts (Table 1-4) to obtain the final hierarchical model ‘Figure 3’:.

Table 1. The scheme weight of the function layer.

	C11	*C12*	C13	*C14*	C15	*C16*	*C17*
weight value	0.163	0.144	0.131	0.148	0.114	0.144	0.156

Table 2. The scheme weight of the intelligency layer.

	C21	*C22*	C23	*C24*	C25
weight value	0.225	0.167	0.191	0.214	0.203

Table 3. The scheme weight of the security layer.

	C31	*C32*	C33	*C34*
weight value	0.259	0.231	0.226	0.283

Table 4. The scheme weight of the aesthetic layer.

	C41	*C42*	C43	*C44*	C45
weight value	0.183	0.237	0.167	0.241	0.172

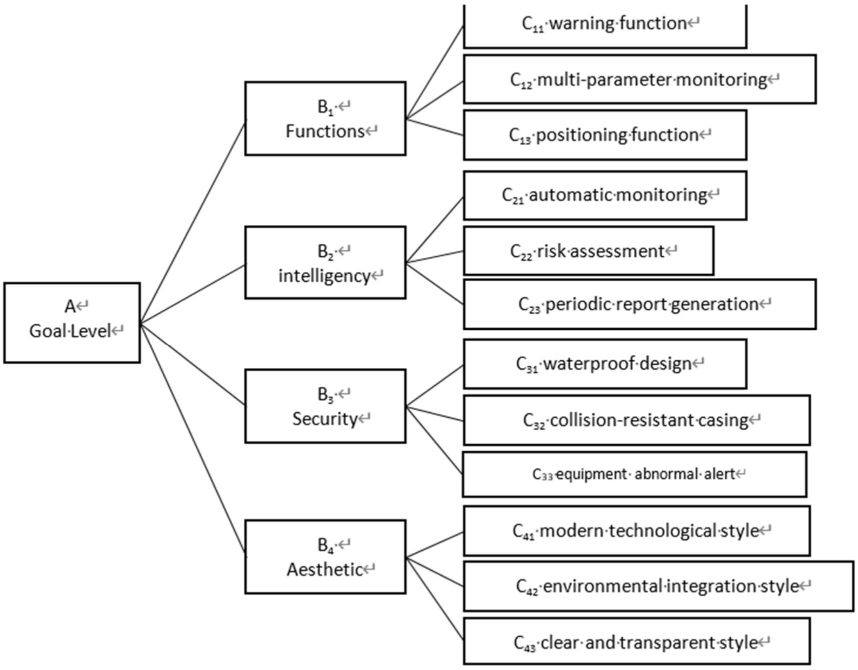

Figure 3. Float type water quality monitoring equipment level model.

Once the indicators for the quasi-measurement and programme levels were established, the comparison of the four quasi-measurement level indicators was carried out before comparing the 12 programme level indicators with each other. In order to make the decision-making structure more objective and professional, the assignments were made by three technical workers of water quality monitoring equipment, two students of environmental engineering, three students of automation, and five designers who rated each parameter on a scale of 1-9. The judgement matrix A is as follows:

$$A = \begin{bmatrix} a11 & a12 & \dots & a1n \\ a21 & a22 & \dots & a2n \\ \dots & \dots & \dots & \dots \\ an1 & an2 & \dots & ann \end{bmatrix}$$

Where a_{ij} indicates the importance of X_i relative to X_j for a, the assignment of a_{ij} is usually scored by experts in the relevant field or based on the data from the questionnaire survey, and $a_{ij} \times a_{ji} = 1$. The eigenvectors under the eigenvalues of the judgement matrix can correspond to the weights of each indicator, and the weight values of the judgement matrix are calculated according to the square root method, resulting in the integrated weights of the hierarchical performance of buoy-type water quality monitoring equipment as shown in Table 5:

Table 5. Weight value of each index of float type water quality monitoring equipment.

Goal Level	Criterion Level	weight value	CR	Alternative Level	weight value	CR
The hierarchical performance Requirements of buoy-type water quality monitoring devices	B_1 Functions	0.28	0.0715	C_{11} warning function	0.09	0.0633
				C_{12} multi-parameter monitoring	0.19	
				C_{13} positioning function	0.72	
	B_2 Intelligency	0.13		C_{21} automatic monitoring	0.57	0.0519
				C_{22} risk assessment	0.07	
				C_{23} periodic report generation	0.36	
	B_3 Security	0.54		C_{31} waterproof design	0.57	0.0519
				C_{32} collision-resistant casing	0.07	
				C_{33} equipment abnormal alert	0.36	
	B_4 Aesthetic	0.05		C_{41} modern technological style	0.59	0.0136
				C_{42} environmental integration style	0.08	
				C_{43} clear and transparent style	0.33	

According to the weighting analysis of the first-level indicators, it can be concluded that the performance ranking of buoy-type water quality monitoring equipment: Security＞ Functions ＞ Intelligency＞ Aesthetic, i.e., when designing the scheme, priority should be given to Security and Functions, and based on which the design elements of Intelligency and Aesthetic can be added further. According to the weighting analysis of the secondary indicators, the ranking of solutions under each indicator can be obtained: in Security, waterproof design＞ equipment abnormal alert＞collision-resistant casing; in Functions, positioning function > multi-parameter monitoring > warning function; in Intelligency, automatic monitoring > periodic report generation > risk assessment; in Aesthetic, modern technological style＞clear and transparent style＞environmental integration style. The consistency test was performed on the above data, and the CR value was less than 0.1, which passed the consistency test.

3 Implementation

3.1 Design orientation and rendering

Based on the results of the weighting analysis of the design elements of the buoy-type water quality monitoring equipment, the product design process and method are adopted to design an advanced buoy-type water quality monitoring equipment. The design gives priority to the safety and function realisation of the water quality monitoring device, based on which some intelligent technologies are added and the shape is optimised.

The main function is to monitor natural waters, living reservoirs and other environments with high water quality requirements, automatically monitor various indicators of the water body and regularly generate analysis reports. When the water body is polluted, it can quickly notify the staff at the central control terminal and the relevant government departments, so as to keep the water body pure in time. In terms of aesthetics, a bionic design is introduced, inspired by the jellyfish, a creature that represents benign waters, which is cleverly combined with modern technological styles. The smooth lines and transparent materials of the bionic design show the harmonious symbiosis between technology and nature. The unique and futuristic appearance of the design not only makes the device functionally excellent, but also aesthetically gives the user a pleasant and intimate feeling, and promotes the public's concern and participation in environmental protection. The design of the buoy-type water quality monitoring equipment is shown in the ‘Figure 4’ and ‘Figure 5’.

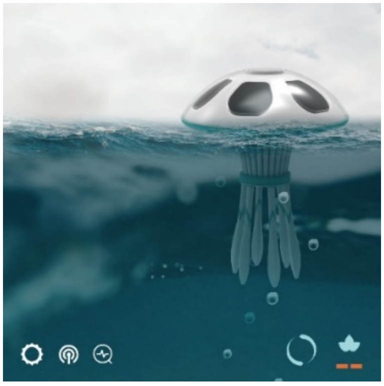

Figure 4. Design renderings.

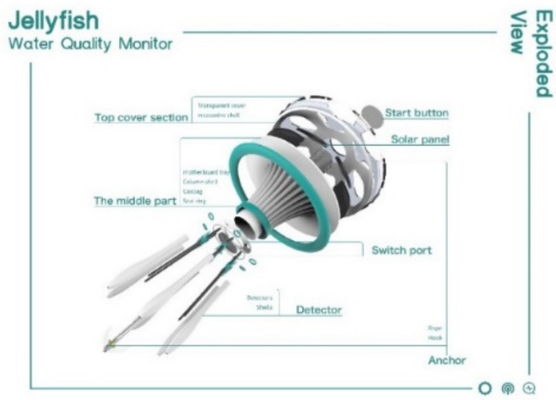

Figure 5. Product exploded view.

3.2 Functional analysis of buoy-based water quality monitoring equipment

(1) Locating problematic water sources‘Figure 6’. Integrating the GPS positioning system and geographic information system, it can accurately obtain the location information of the buoys, and monitor a variety of water quality parameters through the sensor network, and transmit the data to the cloud platform in real time. Combined with the principle of fluid dynamics to

analyse the flow of the water body, it provides multi-mode position feedback so that the staff can clearly understand the monitoring position. At the same time, the device has the ability to move autonomously, and can actively adjust its position according to the monitored changes in water quality, so as to achieve more effective water detection. Equipped with a real-time alarm system and historical data logging, it ensures that timely alarms can be issued in the event of water quality abnormalities, while leaving data for problem tracing.

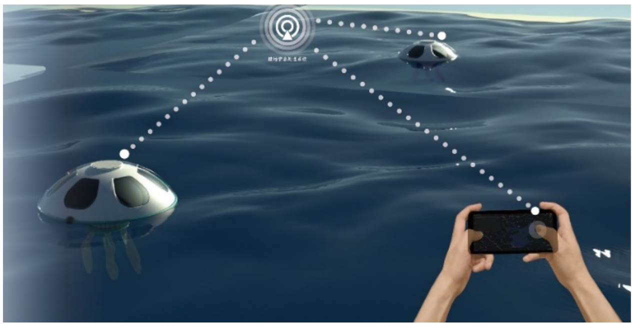

Figure 6. Positioning function renderings.

(2) Multi-parameter analysis‘Figure 7’. By integrating a variety of advanced water quality sensors, including electrochemical sensors, optical sensors, etc., it is able to simultaneously monitor multiple key water quality parameters, such as dissolved oxygen, pH, turbidity, temperature, ammonia nitrogen, and so on. Multi-parameter monitoring not only provides comprehensive water quality information, but also helps to gain an in-depth understanding of the comprehensive condition of the water body.

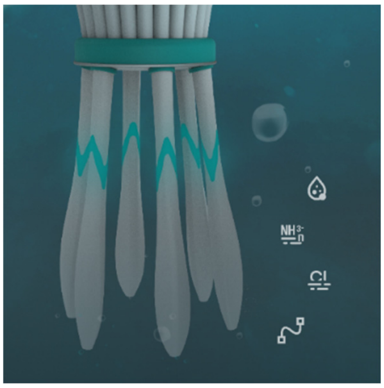

Figure 7. Multi-parameter analysis renderings.

(3) Automatic monitoring. Through the integration of advanced sensing technology and autonomous movement capability, the device is able to achieve automatic and continuous monitoring of water quality parameters without human intervention, thus improving the real-time and efficiency of monitoring. In addition, the device is equipped with autonomous movement capability, which can automatically adjust its position according to the monitored water quality data and preset movement planning to more effectively cover different areas of the water body, further improving the comprehensiveness and depth of monitoring.

(4) Abnormal alarm‘Figure 8’. By integrating a real-time alarm system into the equipment, once abnormal water quality parameters are detected, an alarm is instantly sent to the management system and relevant personnel are notified. The automatic anomaly alarm system can quickly respond to water quality problems, provide timely warning to prevent water pollution or other problems.

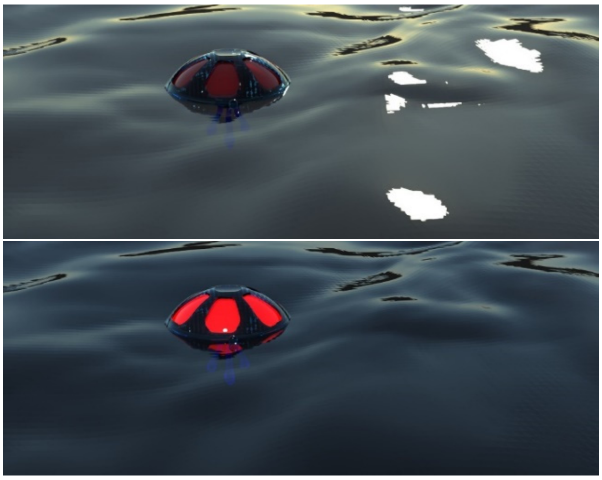

Figure 8. Exception alert renderings.

4 Conclusions

Throughout the research process, I have deeply explored the cutting-edge technologies and methods in the field of water quality monitoring, screened out the market demand through the KJ method, and established a set of scientific and reasonable functional demand system for buoy-type water quality monitoring equipment by using the AHP analysis method. In the modelling design, the bionic design is combined with the modern technology style, which requires the equipment not only to have excellent technical performance, but also to have an attractive appearance design in order to increase the public's attention to the protection of water bodies. This comprehensive study not only provides theoretical support for the design and improvement of buoy-type water quality monitoring equipment, but also provides useful reference and inspiration for further development and innovation in the field of water environment monitoring.

In future work, the intelligent design of water quality monitoring equipment can be further deepened, combining advanced technologies such as artificial intelligence and big data analysis to improve the autonomous learning and adaptability of the equipment. At the same time, it should also continue to refine the application scenarios of the equipment, such as sea water quality monitoring, ecological protection of pristine waters, and other fields, in order to better meet the monitoring needs under the segmented scenarios. Ultimately, it is hoped that this research will provide useful ideas and methods for building smarter, safer and more aesthetically pleasing water quality monitoring devices.

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